R&D on the Superconducting ERL

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Statement of the problem: HOMs and wakefields

- There is no SRF ERL cavity available for β=1, high average current ($\geq$100 mA).
- The beam wakefields generate a huge amount of power over a wide spectral range. This power must be removed from the LHe system and disposed safely.
- For ERL application, HOMs also lead to beam-breakup.

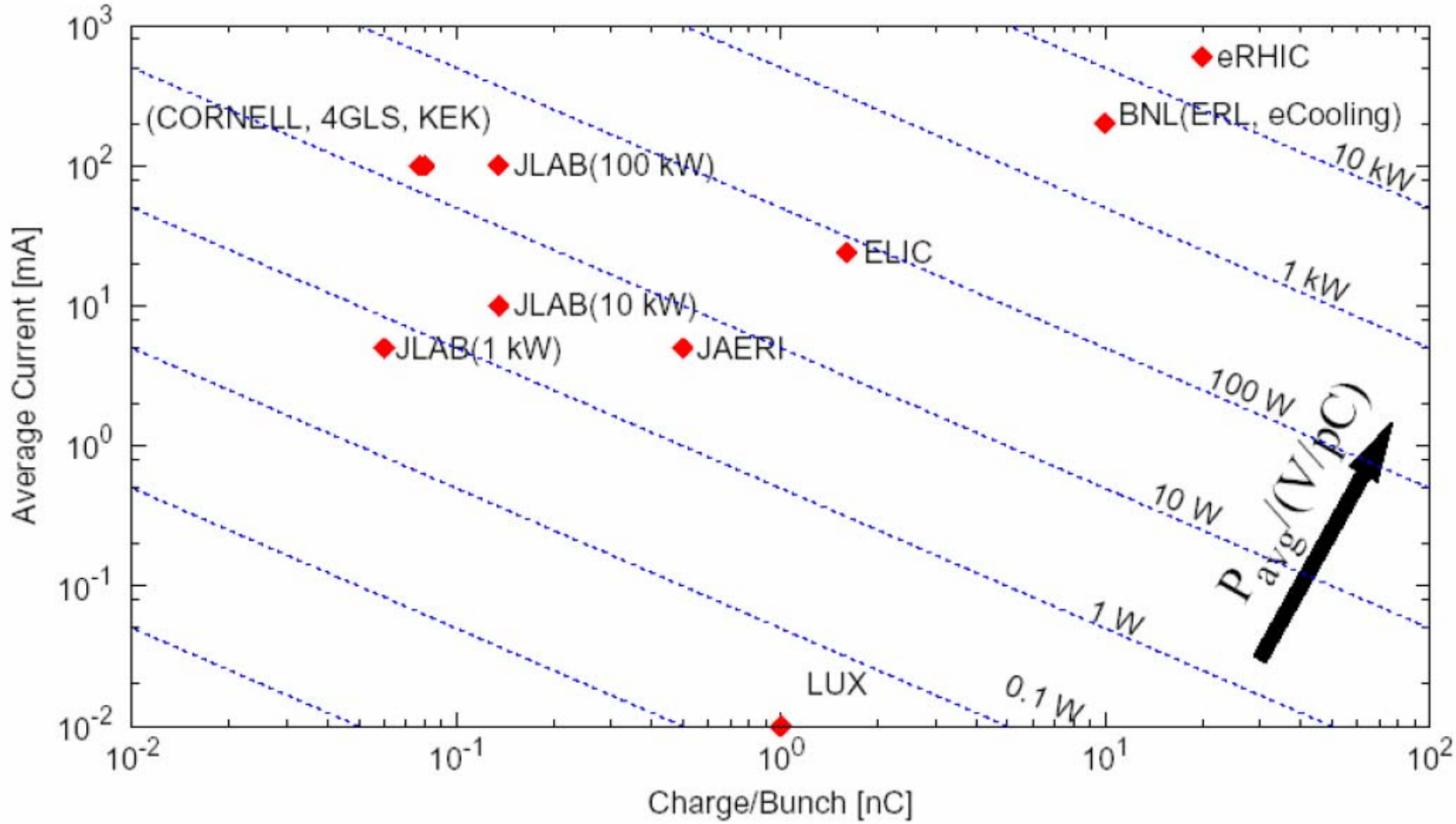
Loss factor

Approximate loss-factor: $$k_l = \frac{\Gamma(.25) Z_0 c}{4\pi^{2.5} a} \sqrt{\frac{d}{\sigma}} \sqrt{N_c}$$

Given 6×10^{10} electrons per bunch, σ=1.4 mm / 2.7 mm, bunch repetition frequency 28.2 MHz and ERL mode.

Cavity (single)	TESLA 1.3 GHz	BNL 0.7 GHz
K_l (V/pC)	7.8	1.2
Power (kW)	39.6	6.6
Energy spread	30×10^{-4}	5×10^{-4}

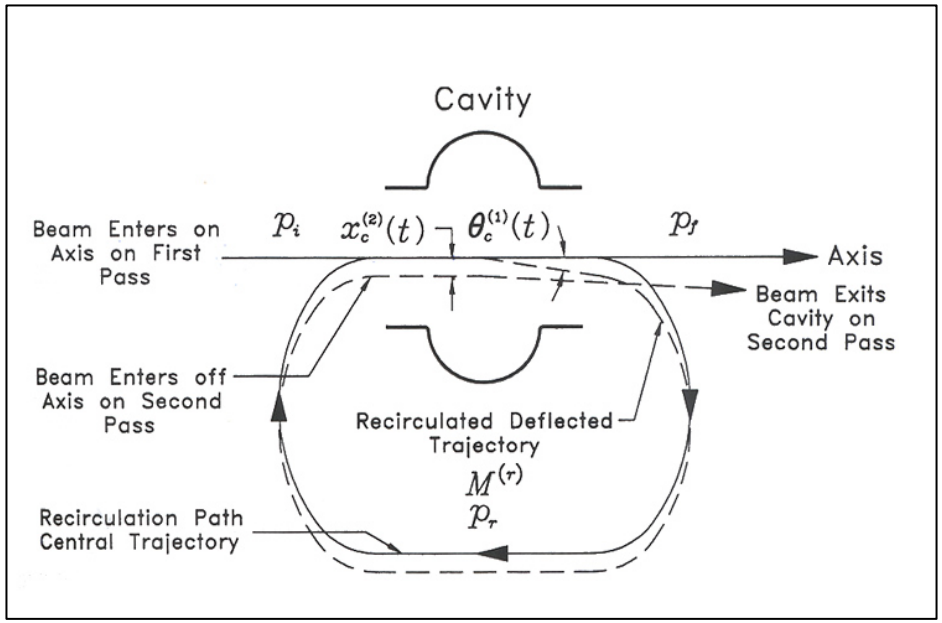
Existing & Future ERLs



*** Avg. Power Normalized to 1 V/pC

Beam breakup

$$I_{th} \propto \frac{1}{\omega^2 Q_m}$$



Some solutions:
1. A lower operating frequency
2. Strong damping of HOMs
3. Large iris diameters and beam pipe

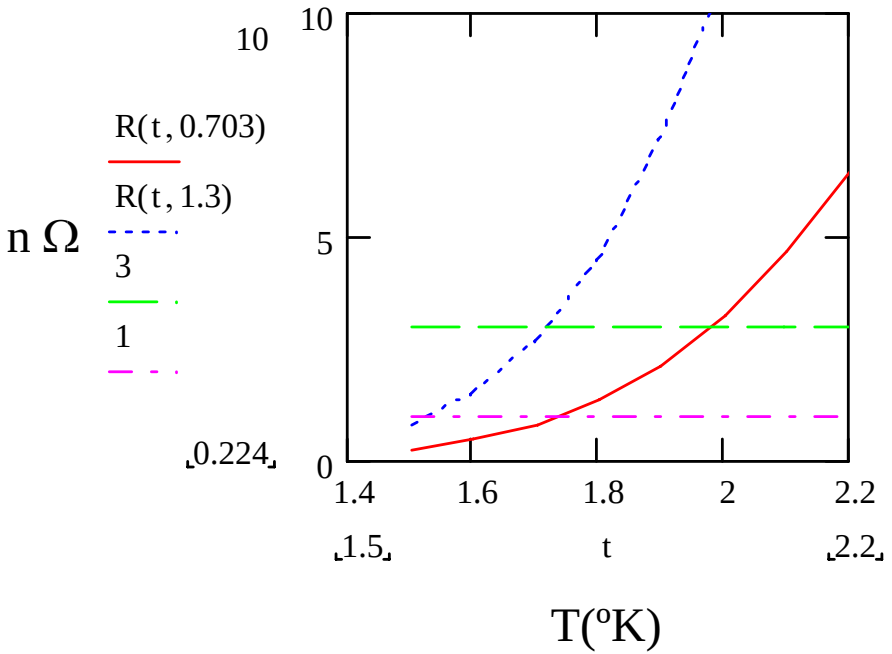
Courtesy:
Geoffrey Krafft

Choice of frequency – additional considerations

- The lowest frequency linac structure JLAB can handle in existing chemical cleaning is ~700 MHz
- High power CW klystrons (for the photoinjector) exist only at 500, 700 and 1250 MHz.
- Superconductor BCS surface resistance goes down with frequency squared,
- Inexpensive and compact RF exists at 700 MHz or lower (UHF TV transmitters using IOT devices)

BCS and residual resistance

$$R_{BCS} = 2\cdot 10^{-4}\,\frac{1}{T}\left(\frac{f\,(GHz)}{1.5}\right)^{2}\exp\left(-\frac{17.67}{T}\right)$$



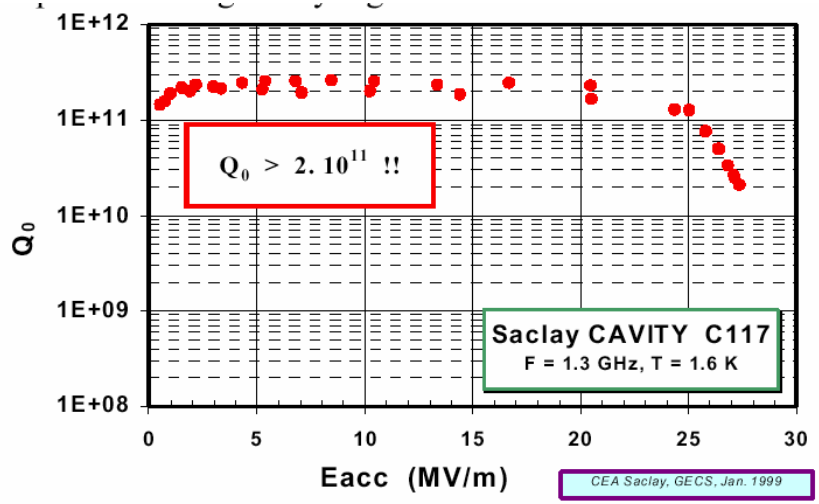
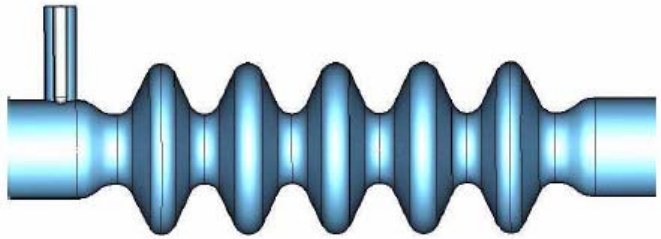


Figure 2 – Residual resistance as low as 0.5 nΩ is actually measured on large area cavities, giving an intrinsic quality factor Q_0 exceeding 2.10^{11}.

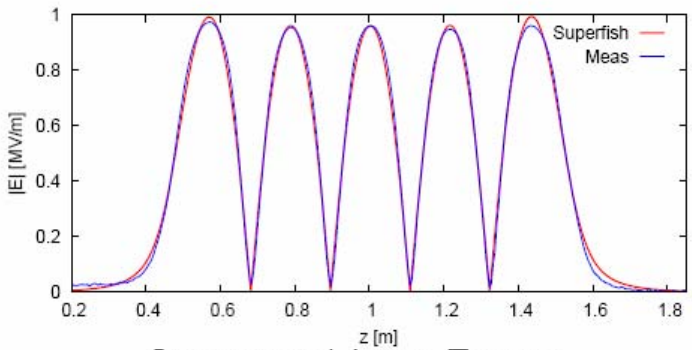
Residual resistance <1 nΩ possible

Main Parameters:

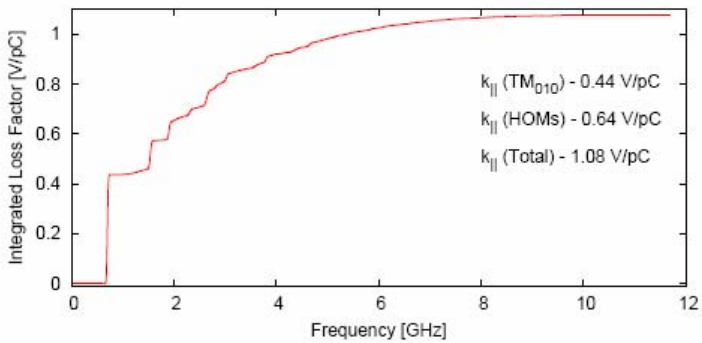
Frequency	703.75 [MHz]
RHIC Harmonic	25
Number of cells	5
Active cavity length	1.52 [m]
Iris Diameter	17 [cm]
Beam Pipe Diameter	24 [cm]
G (Ω)	225
R/Q	403.5 [Ω]
Q BCS @ 2K	4.5×10^{10}
Q_{ext}	3×10^{6}
E_p/E_a	1.97
H_p/E_a	5.78 [$mT/MV/m$]
cell to cell coupling	3%
Sensitivity Factor ($\frac{N^2}{\beta}$)	833
Field Flatness	96.5 %
Lorentz Detuning Coeff	1.2 [Hz/MV/m]
Lowest Mech. Resonance	96 [MHz]
$k_{\|\|}$ ($\sigma_z - 1cm$)	1.1 [V/pC]
$k_{\perp}$ ($\sigma_z - 1cm$)	3.1 [V/pC/m]
HOM Power (10-20 nC)	0.5-2.3 [kW]



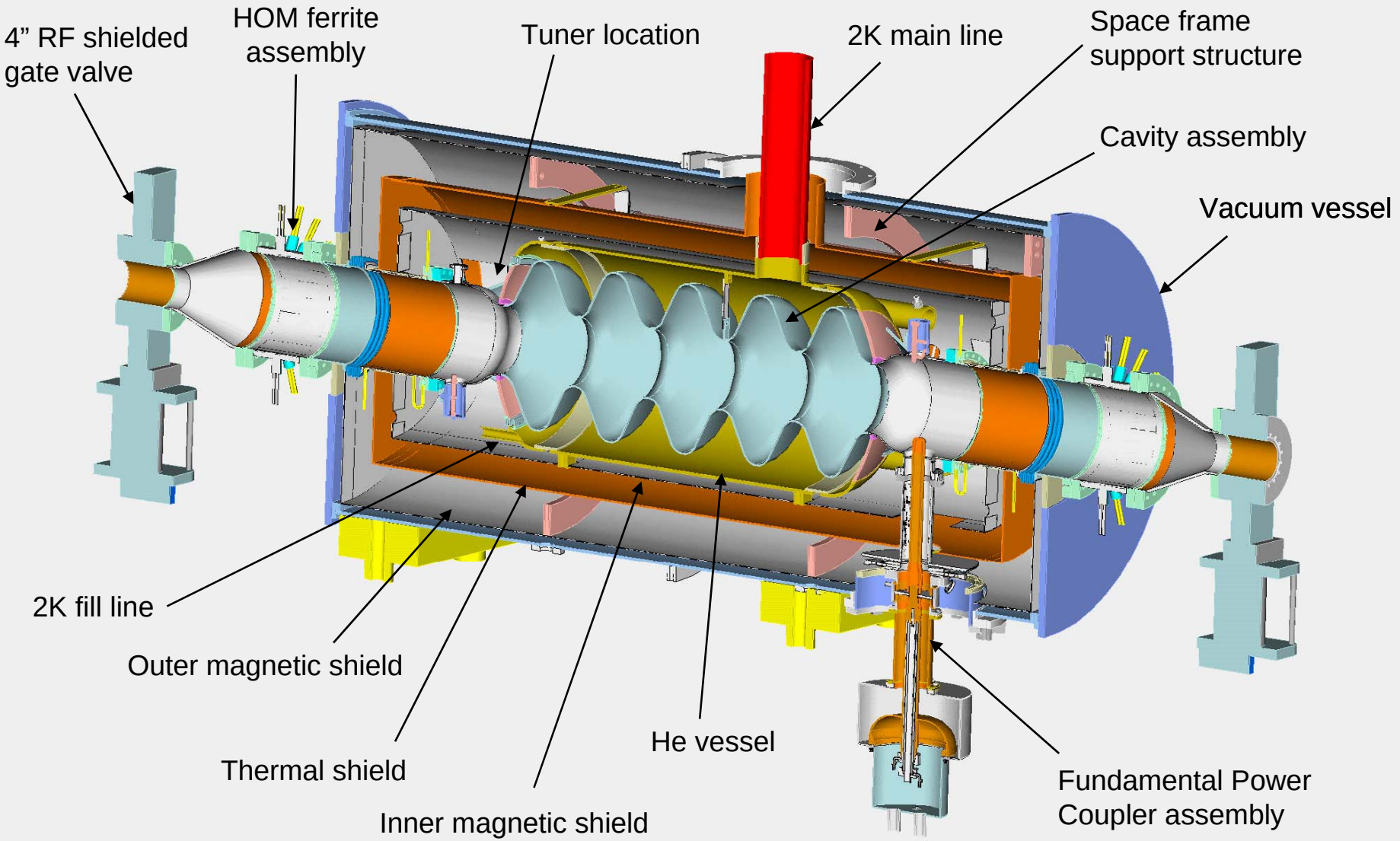
Field Flatness



Integrated Loss Factor



Cryomodule Design



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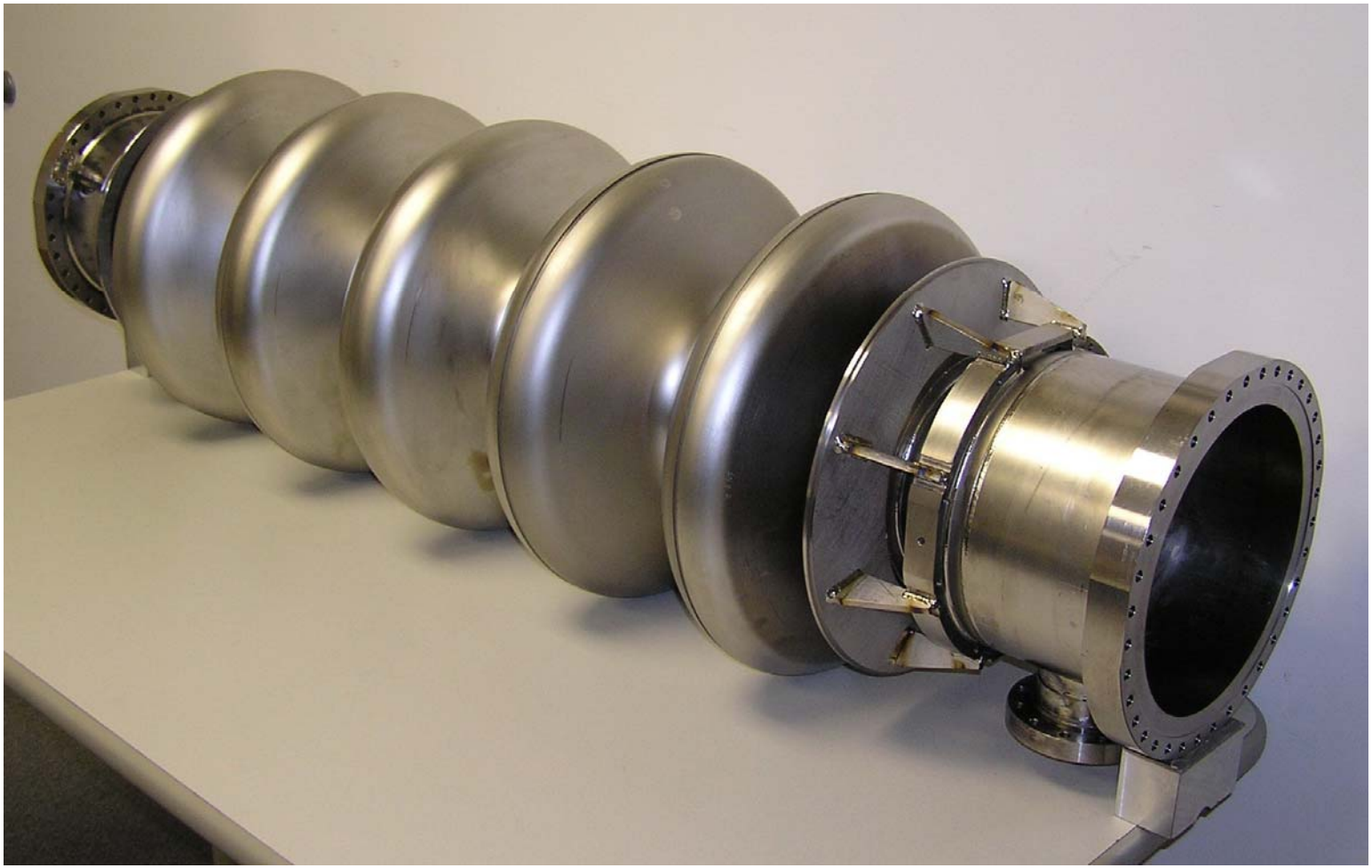
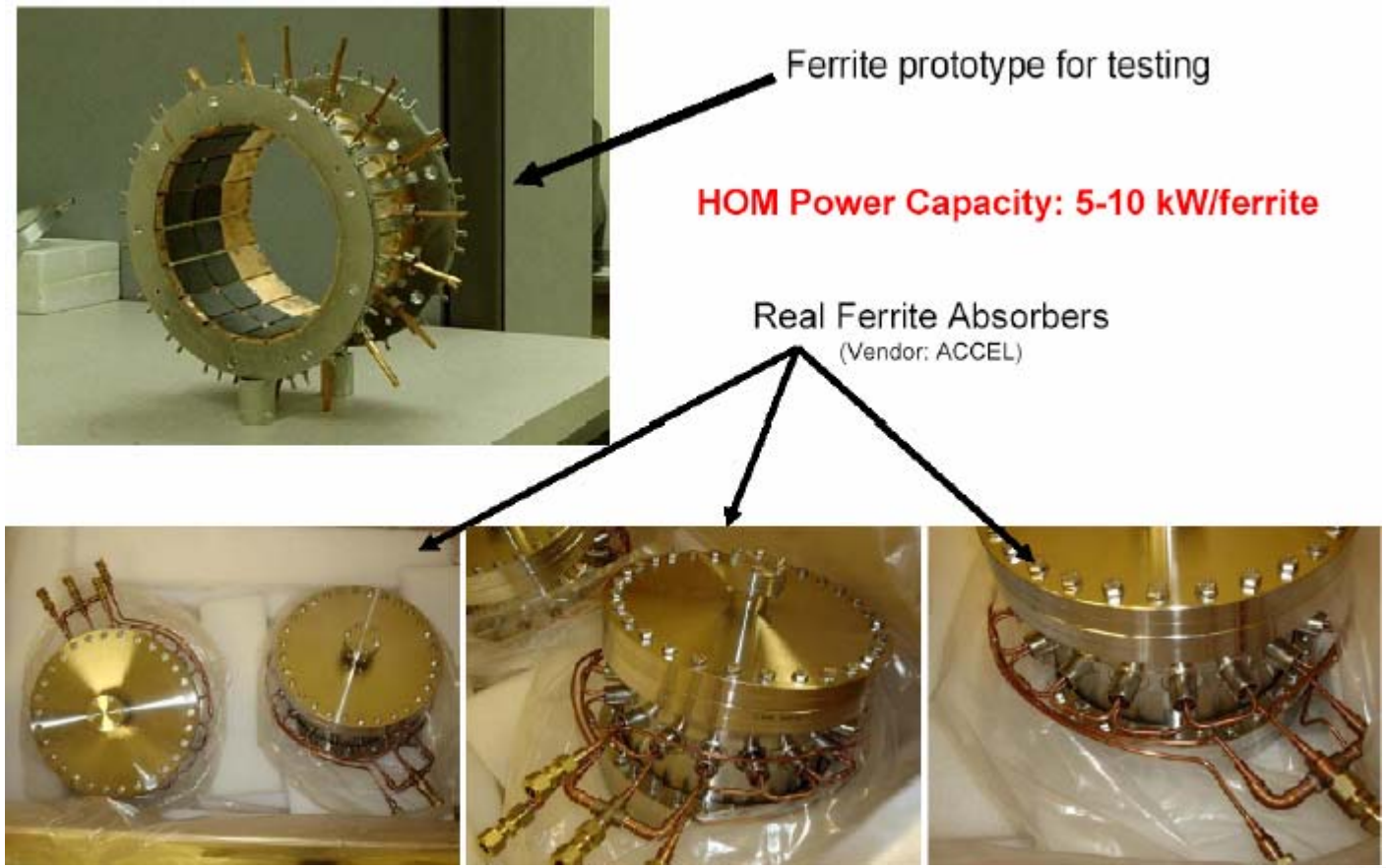
Advanced Energy Systems, Inc.

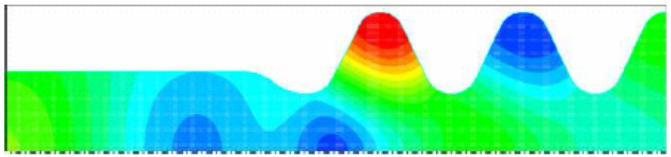


Ferrite HOM dampers – use Cornell development

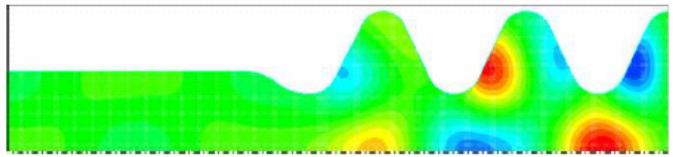


Some Dipole Modes of Interest (B_ϕ)

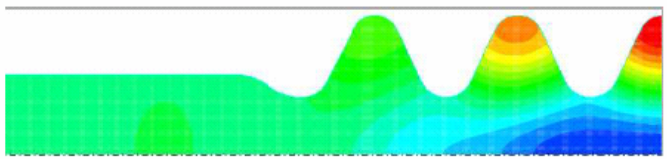
959 MHz, Q_{ext} - 8×10^3



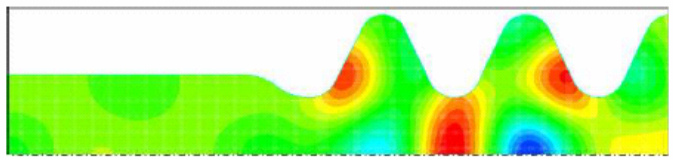
1.771 GHz, Q_{ext} - 1.2×10^4



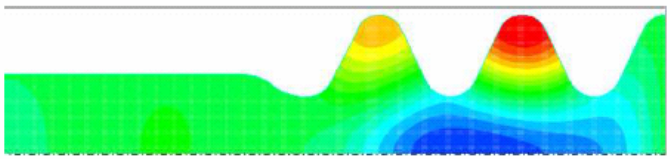
965 MHz, Q_{ext} - 1.4×10^3



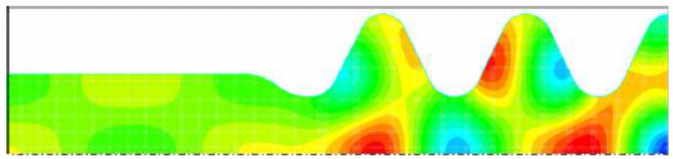
1.776 MHz, Q_{ext} - 7×10^3



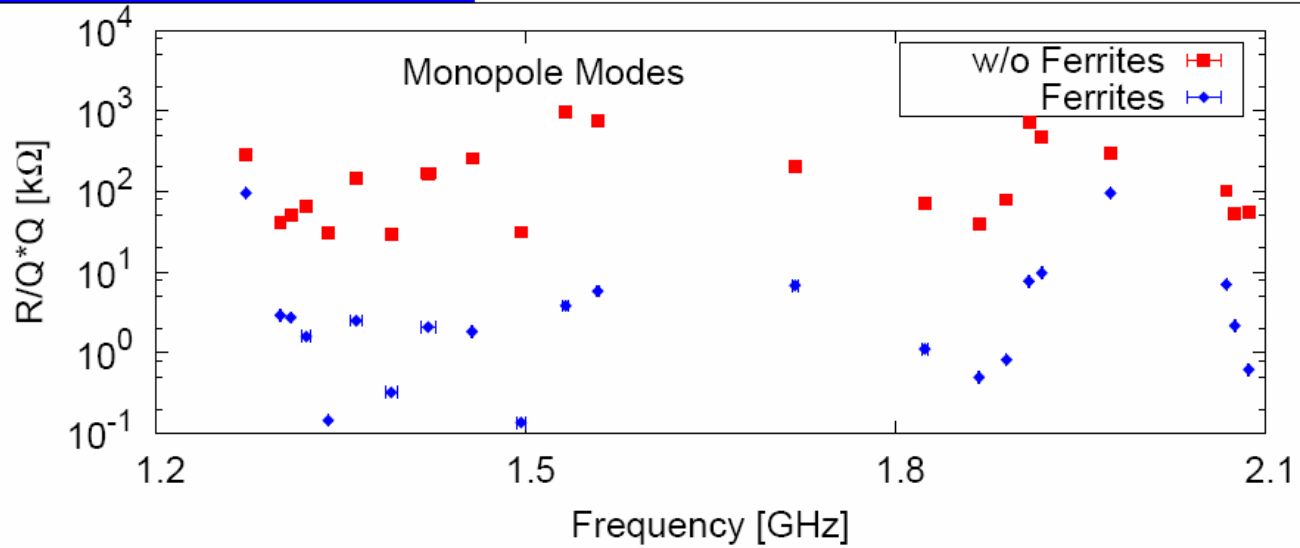
973 MHz, Q_{ext} - 3.3×10^2

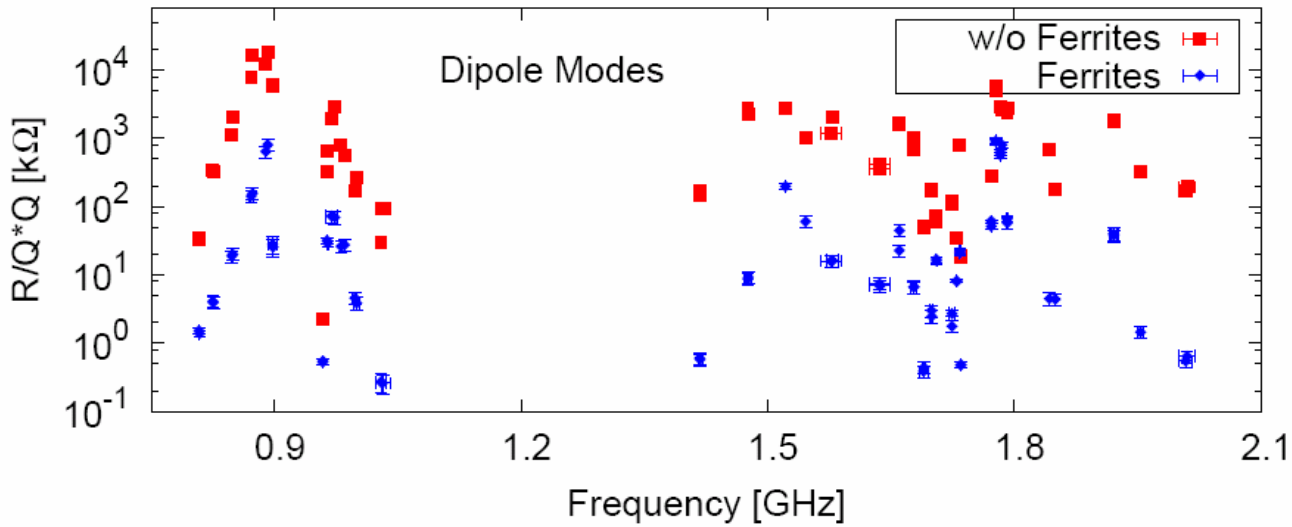


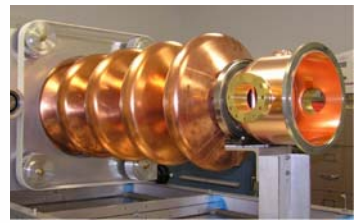
1.781 MHz, Q_{ext} - 1×10^4



Higher Order Modes

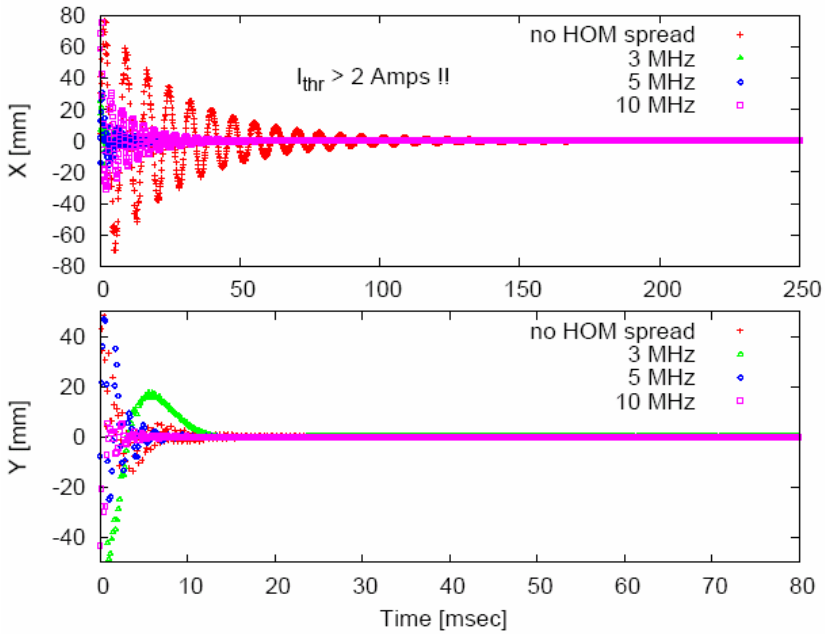




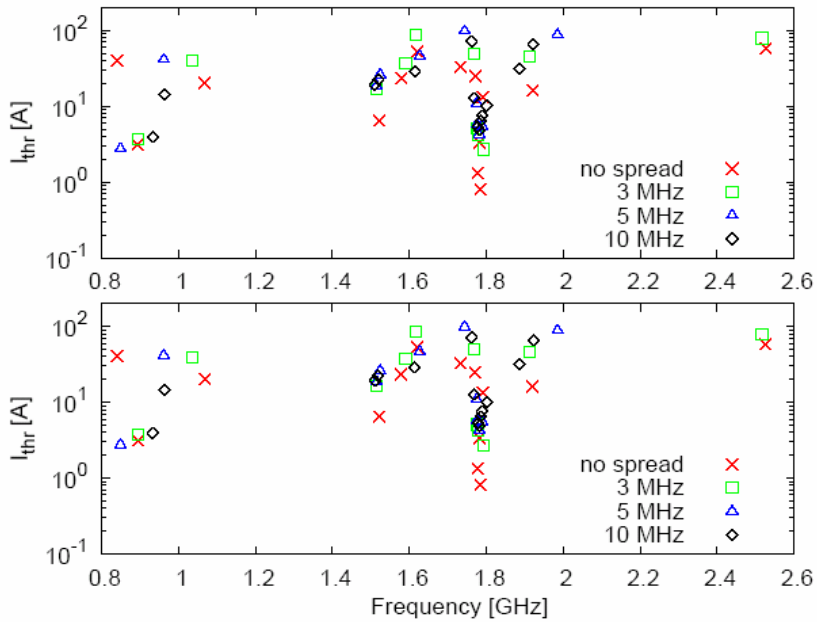


Multibunch BBU

TDBBU



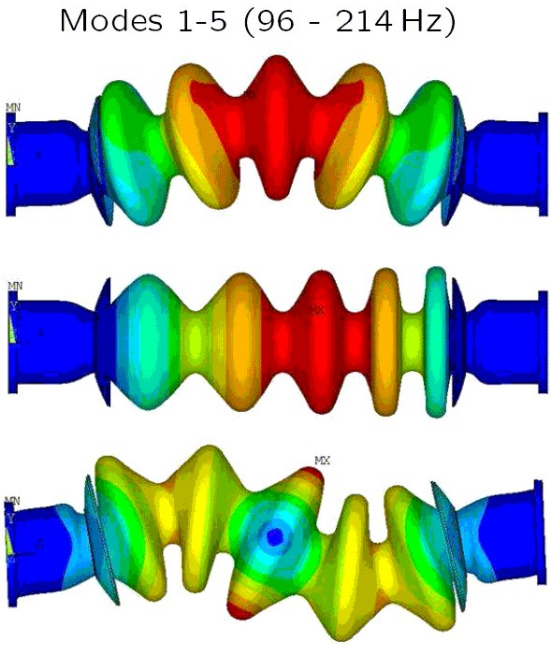
MATBBU



Electron Cooling Configuration (4 Cavities - 54 MeV)

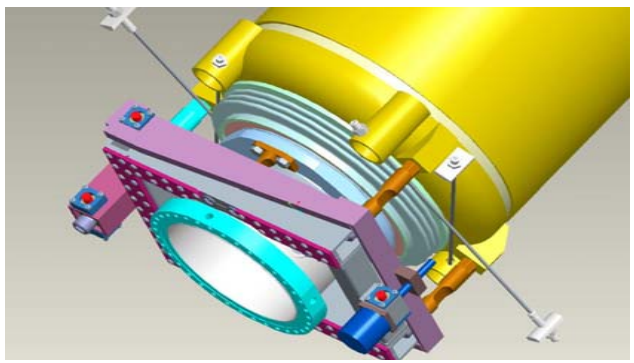
Simulations for eRHIC sized machine yet to be done,
but starting with a well damped cavity is a good beginning.

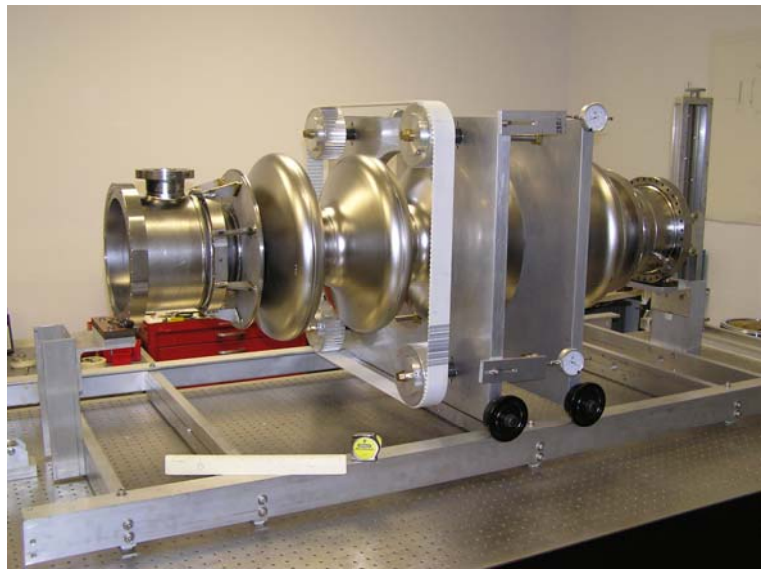
Mechanical Resonances (D. Holmes - FEA)



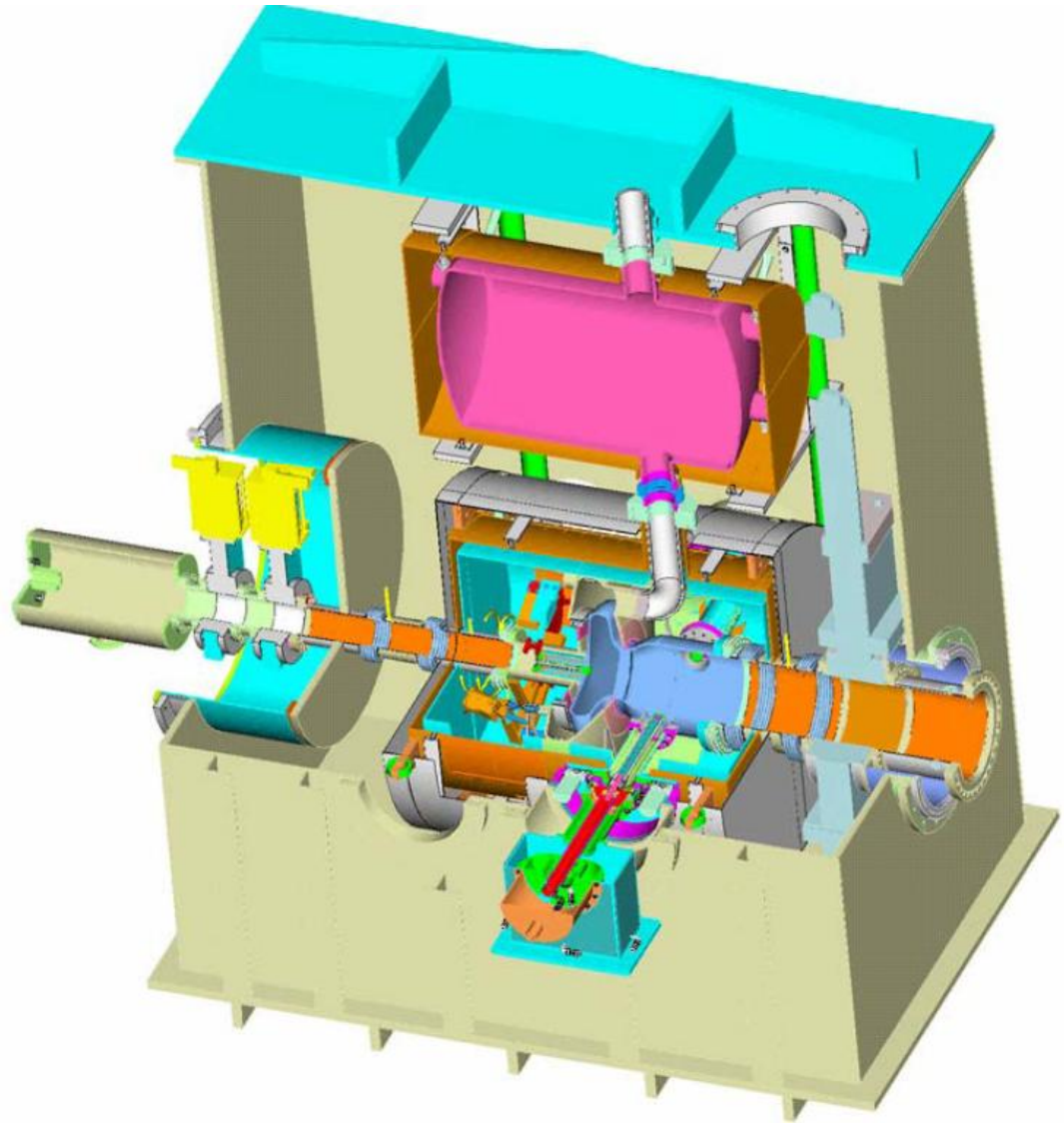
This cavity is stiff!
(important for Lorentz detuning and acoustic vibrations)

Compact tuner, slow fast tuning, 475 kHz range.



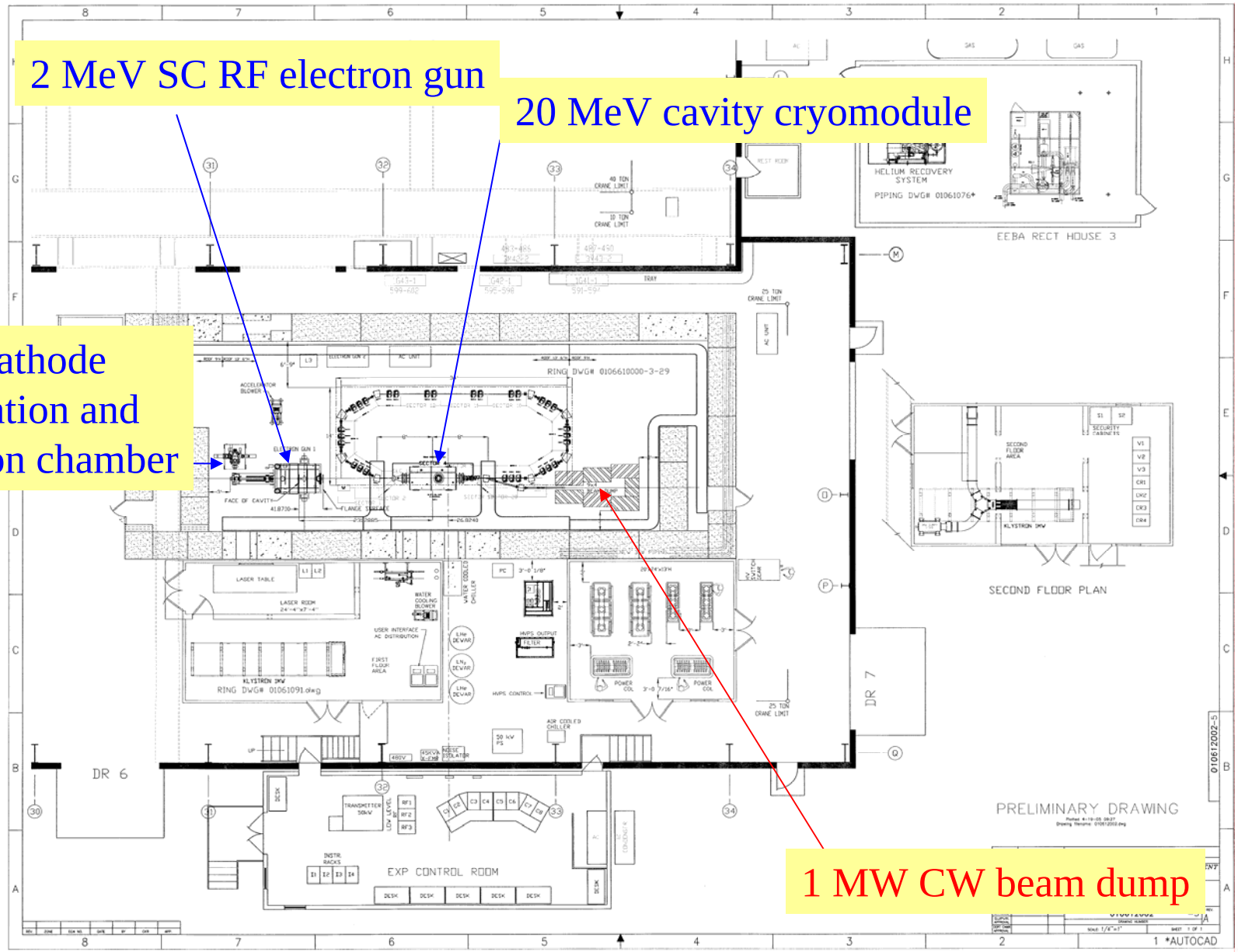


Superconducting RF gun under development.
Possibly could support polarized electrons production.



ERL
Under construction

BNL ERL Facility at building 912



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